SUMMARY REPORT

Santa Clara Valley Water District
Groundwater Vulnerability Pilot Study

Investigation of MtBE Occurrence
Associated with
Operating UST Systems

Volume 1 of 3

July 22, 1999
6730.00-31

LFR
LEVINE • FRICKE
1900 POWELL STREET, 12TH FLOOR
EMERYVILLE, CALIFORNIA 94608-1827
(510) 652-4500/FAX (510) 652-2246
Website: www.LFR.com

STUDY TEAM

SANTA CLARA VALLEY WATER DISTRICT

5750 Almaden Expressway, San Jose, California, 95118-3686 (408) 265-2600
David Matthews, Co-Project Manager
Christine Tulloch, Co-Project Manager
Tracy Hemmeter, MtBE Project Manager
James Crowley, P.E., Engineering Unit Manager

CONSULTANT TEAM

MANAGEMENT

LFR Levine·Fricke, 1900 Powell Street, Emeryville, California 94608-1827 (510) 652-4500
Thomas M. Johnson, R.G., C.HG., Program Manager
Jenifer J. Beatty, R.G., C.HG., Deputy Program Manager
J. Scott Seyfrield, R.P.S.S., Program Administrator
Eric M. Nichols, P.E., Director of Technical Evaluations
Andrew M. Lojo, R.G., Scheduler/Estimator
Thomas Zakaria, R.G., C.E.G., C.HG., Site Manager
Todd Miller, R.G., C.HG., Site Manager
Julie Sharp, P.E., Site Manager
Noel DeGuzman, Project Coordinator
Jae Anderson, Project Assistant

UST ASSESSMENT SPECIALIST

Jeff Tarter, Integrated Engineering Services,
2391 Zanker Road, Suite 370, San Jose, California (408) 321-0810

MtBE RESEARCH SPECIALIST

Tim Buscheck, P.E., Chevron Research & Technology Company,
100 Chevron Way, Richmond, California (510) 242-5954

CPT CONTRACTOR

Gregg In Situ, 950 Howe Road, Martinez, California 94553 (925) 313-5800

SOIL-GAS SAMPLING CONTRACTOR

InterPhase, 6200 Peachtree Street, Los Angeles, California 90040 (323) 278-7700

SOIL & GROUNDWATER SAMPLING CONTRACTORS

Precision Sampling, Inc., 47 Louise Street, San Rafael, California 94901 (415) 456-9875
Gregg Drilling, 950 Howe Road, Martinez, California 94553 (925) 313-5800

ANALYTICAL LABORATORY

Alpha Analytics, Inc., 255 Glendale Avenue, Suite 21, Sparks, Nevada 89431 (702) 355-1044

SURVEYOR

Chaudhary & Associates, 3272 Villa Avenue, Napa, California 94558 (707) 255-2729

CONTENTS

Executive Summary iii

1.0 Introduction 1
  1.1 Background 1
  1.2 Objectives 2
  1.3 Report Organization 3

2.0 Site Selection and Access 4
  2.1 Site Selection Process 4
  2.2 Access Process 6
  2.3 Composition of Study Population 6

3.0 Methods 8
  3.1 Site Inspections 9
  3.2 Lithologic/Hydrogeologic Characterization 9
  3.3 Soil-Gas Sampling and Analysis 10
  3.4 Soil Sampling and Analysis 10
  3.5 Groundwater Sampling and Analysis 11
  3.6 Site Survey 12
  3.7 QA/QC of Analytical Data 12
  3.8 Statistical Data Evaluation Method 13

4.0 Study Findings 14
  4.1 Findings Related to Occurrence 15
  4.2 Findings Related to Release Mechanism 18
  4.3 Findings Regarding Fate and Transport of MtBE 22
  4.4 Off-Site Investigations 24
  4.5 Comparison with Other Occurrence Studies 26
  4.6 Application of Study Findings to a Groundwater Vulnerability Assessment 27

5.0 Summary of Key Study Findings 29

6.0 Recommendations 30

7.0 Limitations 31

References 32

Tables

1 Criteria for Site Ranking 4
2a Summary of Selected Sites That Granted On-Site Access 5
2b Summary of Selected Sites That Restricted On-Site Access 5
3 Facility Data for Sites Selected for Study 6
4 Summary of System Components at Study Sites 7
5 Designation of Sampling Targets 9
6 Number of Soil-Gas, Soil, and Groundwater Samples Submitted for Analysis 12
7 Detections of MtBE in Soil and Groundwater Relative to System Components and Site Conditions 14-15
8 Concentration Ranges and Number of Sites Reporting MtBE in Groundwater, Soil, and Soil Gas 15
9 Comparison of MtBE Detection in Soil Gas and Soil Relative to Presence or Absence of MtBE in Groundwater 16
10 Evaluation of Lithology and MtBE Releases 17
11 Summary of Reported Concentrations of Other Oxygenates 17
12 MtBE Detections Relative to Facility Characteristics 18-19
13 Results of Statistical Data Evaluations, Relationships Between Presence of MtBE in Groundwater and UST System Components 20
14 Correlation of System Components to Detections of MtBE 21
15 Frequency of MtBE Detection for On-Site and Off-Site Investigations 25
16 Summary of MtBE Detection Frequency for Other Studies 26
17 SCVWD Ongoing Study Results, Current MtBE Concentration Ranges in Groundwater 27

Figures

1 Correlation of MtBE in Groundwater to MtBE in Soil 23
2 Histogram of Distance from Soil/Groundwater Sampling Locations to UST System Components for On-Site and Off-Site Investigations 24
3 MtBE Concentration in Groundwater Relative to Distance from UST System 25
4 Benzene Concentration in Groundwater Relative to Distance from UST System 26

Appendices

1 Examples of Information Distributed to Potential Study Participants
2 Site Inspection Forms
3 Investigation and Laboratory Procedures
4 Summary Laboratory Data Tables
5 Statistical Methodology for Evaluating MtBE Occurrence Associated with UST Components
6 Feenstra Methodology

Volume 2 Site Reports

Volume 3 Laboratory Certificates

Executive Summary

The Santa Clara Valley Water District (SCVWD) is concerned with the protection of drinking water resources. Concerns about possible undetected releases from 1998-upgrade-compliant fueling facilities prompted the SCVWD Board of Directors to commission a pilot study (“the Study”) to evaluate if methyl tert-butyl ether (MtBE) is being released at these underground storage tank (UST) facilities as part of an assessment of the vulnerability of groundwater resources in Santa Clara County. The purpose of the Study is to determine the occurrence of MtBE at sites with operating USTs and identify if MtBE is being released undetected at facilities with 1998-upgrade-compliant UST systems. Secondary objectives include an evaluation of various release scenarios to determine possible relative contribution to MtBE occurrence in the subsurface, and data evaluation to assess the fate and transport of MtBE from the release point to groundwater and the role that various UST systems play in the potential for undetected releases to the environment. Study objectives were met by conducting a soil and groundwater investigation of 28 facilities within the Santa Clara Valley Water District with operating 1998-upgrade-compliant UST systems.

Site Selection. The facilities included in the Study were chosen using selection criteria designed to minimize the influence of potential releases from prior UST systems that did not meet the 1998 upgrade requirements. The Study sites were selected from an initial population of approximately 2,000 sites in Santa Clara County reporting petroleum use and storage in the Bay Area Air Quality Management District. Sites identified as having aboveground storage tanks only or non-gasoline use were removed from the list. Initially, all sites on the SCVWD Leaking Underground Storage Tank database were removed from consideration; however, some of those sites were subsequently reevaluated. Approximately 80 sites were then selected for file review using selection and ranking criteria developed for the project. Attempts were made to include a cross section of UST system components and depth-to-water conditions and to avoid sites with known or suspected impacts from neighboring facilities. Through this process, a study population of 28 sites was selected for field investigation.

Field Investigation. Full on-site access was negotiated for 17 of the 28 selected sites. The scope of the investigation conducted at those sites included a site inspection focusing on the UST system components; lithologic characterization using cone penetrometer testing; a soil-gas survey; and soil and groundwater sampling. At the other 11 sites, investigation activities were conducted in off-site areas and included off-site inspections to evaluate facility layout and accessibility; lithologic characterization using continuous soil coring; and soil and groundwater sampling. Soil and groundwater samples were collected using state-of-the-art dual tube sampling technology and were analyzed for MtBE and other oxygenates and petroleum hydrocarbons using gas chromatography/mass spectroscopy.

Results. Groundwater was encountered at 27 sites. MtBE was detected in groundwater at 13 of the 27 sites investigated, at concentrations ranging from approximately 1 microgram per liter (µg/L) to 200,000 µg/L; of those 13 sites, concentrations over 1,000 µg/L were detected at 5 sites. These data indicate that MtBE may be present in groundwater at approximately 50% of the UST facilities that meet 1998 upgrade requirements within Santa Clara County. Study results indicate that the likelihood of MtBE occurrence in groundwater is not strongly related to lithology or depth to groundwater.

Petroleum constituents were not detected in groundwater at 5 of the 13 sites that had detections of MtBE in groundwater. The greater frequency of MtBE detections relative to petroleum constituents likely results from the following factors:

- Increased solubility and mobility of MtBE relative to petroleum compounds
- Possible vapor release and migration of MtBE in the vapor phase
- The relatively large fraction of MtBE in the fuel mixture relative to petroleum compounds
- Recalcitrance of MtBE to biological degradation relative to petroleum compounds

Other oxygenates detected included tert-butyl-alcohol (TBA), tertiary-amyl methyl ether (TAME) and ethyl tertiary-butyl ether (ETBE). TBA was detected in groundwater at 3 sites (maximum concentration of 12,000 µg/L), TAME was detected at 2 sites (maximum concentration of 95 µg/L) and ETBE was detected at one site (maximum concentration of 5.2 µg/L). These other oxygenates were detected only in those groundwater samples with a concentration of MtBE of over 1,000 µg/L.

A statistical analysis of data comparing those sites with MtBE detections in groundwater with those sites with no MtBE detected in groundwater indicated a statistically significant association between the occurrence of MtBE and the presence of an assisted vapor recovery system versus a balanced vapor recovery system. No other significant associations between MtBE occurrence in groundwater and UST system component resulted from the statistical analysis.

For the majority of sites in this Study, it is not clear whether the detected MtBE was released before or after the 1998 UST system upgrades were installed, or during installation of the upgrades. Of the four sites in the Study with no UST use prior to operation of a 1998-compliant system, one site had detections of MtBE in soil gas, soil and groundwater, at a maximum concentration in groundwater of 25,000 µg/L. Those data demonstrate a release of MtBE to groundwater from a facility with a 1998-compliant UST system.

1.0 Introduction

The Santa Clara Valley Water District (SCVWD) is concerned with the protection of drinking water resources. Concerns about possible undetected releases from existing 1998-upgrade-compliant and new fueling facilities prompted the SCVWD Board of Directors to commission a pilot study to evaluate if methyl tert-butyl ether (MtBE) is being released at underground storage tank (UST) facilities of that type, and to assess the vulnerability of groundwater resources in Santa Clara County from such sources. The purpose of this Study is to determine the occurrence of MtBE at sites with operating USTs and identify if MtBE is being released undetected at facilities with 1998-upgrade-compliant UST systems. Secondary objectives include an evaluation of various release scenarios to determine possible relative contribution to MtBE occurrence, data evaluation to assess the fate and transport of MtBE from the release point to groundwater, and the role that various UST systems play in the potential for undetected releases to the environment.

1.1 Background

Since mid-1995, responsible parties have been requested to analyze groundwater samples for MtBE as part of contaminant investigation and monitoring activities at fuel leak sites. As the SCVWD reviewed the resulting MtBE data, concerns were raised about the occurrence, trends, and distribution of MtBE at fuel leak sites with operating UST systems.

The SCVWD conducted a preliminary study of MtBE occurrence and determined that a broader study was warranted to determine (a) if new releases of gasoline are occurring at sites without being detected by the UST monitoring system, and (b) if the facilities have UST systems that meet the 1998 upgrade requirements. The SCVWD began a more detailed evaluation of fuel leak data and in 1997 initiated an internal site-specific study of potential leaking UST systems at fuel leak sites. In addition, SCVWD staff participated on the Governor′s Advisory Panel on the *Evaluation of Fuel Releases from Upgraded Underground Storage Tanks*. The advisory panel was directed to determine if releases are occurring from UST systems that meet the 1998 UST requirements.

In 1997, the SCVWD began to observe significant differences in MtBE concentrations and trends at fuel leak sites with operating USTs, when compared with sites no longer dispensing fuel. Statistics generated by the SCVWD indicated that 83% of fuel leak sites with active USTs detected MtBE, compared to only 59% of sites no longer dispensing fuel. Further, 31% of the operating UST sites reported historical maximum MtBE concentrations in groundwater over 3,500 µg/L, compared to only 6% of non-operating UST sites. Additionally, a significant number of operating UST sites were reporting increasing MtBE concentrations in groundwater; this trend was not observed at the non-operating sites. Further evaluation of site-specific UST system information and MtBE concentrations revealed anecdotal evidence of undetected releases of MtBE at 1998-upgrade-compliant sites. Most notably, in 1998 an operating retail fuel station discovered significant concentrations of MtBE in soil and groundwater beneath the site when conducting an investigation related to the detection of MtBE at a nearby municipal well (Crowley and Tulloch 1998). The site was not an open fuel leak case, and had not reported a gasoline release since 1989.

In May 1998, the SCVWD issued requests for proposals that included a work plan for a Pilot Study to Investigate Operating UST and MtBE Occurrence. LFR Levine·Fricke and its subcontract team (Integrated Engineering Systems, Gregg In Situ, InterPhase, Precision Drilling, Inc., Gregg Drilling, Alpha Analytics, Inc., and Chaudhary & Associates) were selected as the contractor for the District to complete the necessary data collection, compilation, evaluation, and reporting activities. In addition, Tim Buscheck, P.E., of Chevron Research & Technology Company contributed significantly to the planning and execution of this study.

Completion of the investigation activities was made possible through the cooperation of area agencies and the owners and operators of fuel distribution facilities. With appreciation, we recognize the following for their contribution to this study:

AGENCIES

- Gilroy Fire Department
- Milpitas Fire Department
- Mountain View Fire Department
- San Jose Fire Department
- Santa Clara County Department of Environmental Health
- Santa Clara County Fire Department
- Santa Clara Fire Department
- Sunnyvale Department of Public Safety Division of Fires and Public Safety

OWNERS/OPERATORS

- ARCO
- Chevron Products Company
- City of San Jose Mabury Yard
- Olympian Oil Company
- Price/Costco
- Santa Clara County Department of Roads & Airports
- SCVWD Almaden Fueling Facility
- Shell Oil Company
- Tosco/UNOCAL
- United States Postal Service

1.2 Objectives

The primary objective of this pilot Study was to assess whether MtBE is being released undetected from facilities with operating 1998-upgrade-compliant UST systems, and to evaluate the general magnitude of undetected releases and the resulting vulnerability of groundwater and drinking water resources to such releases. A 1998-upgrade-compliant UST system is defined as one that meets the 1998 federal- and state-mandated UST upgrade requirements or the new UST construction requirements (January 1984 or later).

Secondary objectives included:

- Assess if a particular component of or condition at a UST facility (e.g., tanks, piping, surface-water infiltration, etc.) is more or less likely to be a potential source of MtBE to the subsurface

- Assess the fate and transport of MtBE from the release point to groundwater

Results of this study will be used by SCVWD staff to address issues regarding groundwater vulnerability in Santa Clara County. These results also will likely be used by the SCVWD and other interested parties to help develop strategies to reduce groundwater resource vulnerability associated with releases of MtBE.

1.3 Report Organization

This report summarizes the activities conducted and the investigation findings. Presentation of the information has been organized into seven sections:

1.0 Introduction
2.0 Site Selection and Access
3.0 Investigation Methods
4.0 Study Findings
5.0 Summary of Key Study Findings
6.0 Recommendations
7.0 Limitations

In addition, summary data and other references are provided in the appendices (Appendices 1 through 6). Individual Site Reports for each site investigated are appended to this document for further study and reference (Volume 2), along with certifications of laboratory analyses (Volume 3).

2.0 Site Selection and Access

The objective of site selection was to identify a Study population of approximately 30 sites that would yield data representative of conditions in the Santa Clara Valley and that would provide information to assess whether 1998-upgrade-compliant UST systems represent a potential source of MtBE to the subsurface, and to groundwater resources in particular. The SCVWD worked with LFR to compile a list of potential sites within Santa Clara County and the LFR project team then progressively eliminated sites that did not meet the minimum site selection criteria. The selection process focused on sites where (a) the system met the 1998 Upgrade Requirements, and (b) there had been no known release of MtBE based on a review of available regulatory files and databases.

2.1 Site Selection Process

LFR reviewed the Bay Area Air Quality Management District′s database of sites reporting petroleum storage/use. That database identified more than 2,000 sites in Santa Clara County and was used as the preliminary potential site list. Sites identified as having aboveground storage tanks only or non-gasoline use were removed from the list. Initially, all of the sites listed on the SCVWD′s Leaking Underground Storage Tank (LUST) database were removed from consideration because of the potential for those sites to have had MtBE releases before the 1998-upgrade-compliant UST systems had been installed. However, some sites removed from consideration during this step were subsequently reevaluated for potential inclusion in the Study population when site-specific data collected from local fire department UST system files or other sources indicated that the site met the selection criteria. In addition, local agencies and oil company representatives were contacted for sites to include in the Study population.

During additional screening processes, sites were removed from consideration if the UST system (a) did not meet the 1998 upgrade requirements or (b) did not store or distribute gasoline using the current UST system. The resulting list of 180 sites were generally ″ranked″ on the basis of the following criteria:

Table 1 Criteria for Site Ranking

Parameter	Lower Ranking	Higher Ranking
Proximity to a LUST site	< 250 feet	> 250 feet
Depth to groundwater	> 40 feet	< 40 feet
Proximity of the site to a potable-use well(s)	> 2,000 feet	< 2,000 feet
Prior land use	Fuel facility	Other Use

With the assistance and cooperation of the local agencies (identified on page 2 of this report), LFR completed file reviews of approximately 80 of the 180 sites to evaluate system components and site usage histories. On the basis of the information gathered, an effort was made to select sites that reflected a representative cross-section of the different types of 1998-upgrade-compliant UST systems operating in Santa Clara County, including a cross section of the following UST system components:

- Single-walled and double-walled UST construction
- Single-walled and double-walled piping

- Fiberglass and steel UST material

Selection of the final list of 28 sites was an ″iterative″ review process, which by necessity also addressed gaining permission of the site owner/operator to access the site for study. The project team gained access to 17 facilities for on-site investigation, 12 commercial fuel distribution sites and 5 ″private″ facilities (i.e., corporate yards).

Table 2a: Summary of Selected Sites That Granted On-Site Access

Site Owner/Operator	Facility Type	Site ID
Arco	commercial	592
Arco	commercial	593
Chevron	commercial	586
Chevron	commercial	65
Olympian Oil Company	commercial	342
Price/Costo	commercial	505
Shell Oil Company	commercial	405
Shell Oil Company	commercial	287
Tosco/UNOCAL	commercial	598
Tosco/UNOCAL	commercial	595
Tosco/UNOCAL	commercial	73
Tosco/UNOCAL	commercial	261
City of San Jose Mabury Yard	private	289
Santa Clara Co. Dept. of Roads & Airports	private	490
SCVWD Almaden Fueling Facility	private	571
United States Postal Service	private	470
United States Postal Service	private	437

In those areas where the project team was unable to secure access to conduct investigation in on-site areas of a selected site, the project team planned and implemented investigation activities on adjacent right-of-ways or properties.

Table 2b: Summary of Selected Sites That Restricted On-Site Access

Site Owner/Operator	Facility Type	Site ID
Beacon	commercial	196
Beacon	commercial	332
Chevron	commercial	71
Exxon	commercial	597
RAT Petroleum	commercial	489
Rotten Robbie	commercial	594
Rotten Robbie	commercial	596
Spencer Service Inc	commercial	422
USA Petroleum Station	commercial	556
Valley Automated Fuels	commercial	153
Pacific Bell	private	145

2.2 Access Process

To overcome concerns about participating in the Study, the SCVWD and LFR worked with identified site owners to address their concerns, including preparing information packets that were distributed to interested parties. Facility owners who granted access were recognized as ″Good Neighbors to Santa Clara County″ for their participation in the program. Appendix 1 provides examples of the materials distributed to potential participants in the Study.

2.3 Composition of Study Population

The resulting study population consisted of 28 sites with various types of gasoline storage and dispenser systems. Those systems included 65 USTs that had been installed over a period of years. Prior releases had occurred at some of the sites. Table 3 summarizes data for the sites and UST systems selected for study.

Table 3 Facility Data for Sites Selected for Study

Parameter	Number of Sites	Parameter	Number of Sites
TOTAL NUMBER OF SITES: 28			
Prior Release Reported?		*Piping Delivery System*	
Yes	9	Suction	3
No	19	Pressure	25
UST System On Site Before Upgrade?		*Vapor Recovery System*	
Yes	24	Balanced	17
No	4	Assisted	11
Proximity to LUST Site		*Depth to Water*/Lithology[1]	
Less than 250 feet	2	Shallow/coarse grained	6
More than 250 feet	26	Shallow/fine grained	11
Years Since Upgrade		Deeper/coarse grained	6
5 Years or less	21	Deeper/fine grained	4
6 Years or more	2	Did not encounter GW	1
Unknown	5	**TOTAL NUMBER OF TANKS: 65**	
Ownership		*UST Construction*	
Private	6	Single-walled	11
Commercial	22	Double-walled	54
Piping Construction			
Single-walled	2		
Double-walled	24		
Lined trench	2		

1. ″Shallow″ denotes depth to water less than 35 feet; ″deeper″ denotes depth to water greater than 35 feet. Fine- or coarse-grained classification was based on a review of the soil boring and CPT data for each site. At sites where both fine- and coarse-grained sediments were present and neither soil type was predominant, the site was classified as coarse-grained.

The ″unknown″ information category used in tables throughout this report can be largely attributed to sites where investigation activities were conducted in off-site areas. With the exception of one site, UST inspections were not conducted at the 11 sites where off-site investigation activities were conducted.

To our knowledge, the resulting Study population did not contain any known "bias." That is to say, site selection was not made on the basis of an expectation of either a greater or lesser propensity to release MtBE.

Table 4 Summary of System Components at Study Sites

System Components	Site ID	Date Installed	Depth to Water[1] (feet)	UST Present before 1998 Upgrade?	Years Since Upgrade (approximate)
Double-Walled UST, 100% Methanol Compatible with FRP; Double-Walled Underground Fiberglass Piping (3 sites, 6 USTs)	65	1995	66	Yes	4
	505	1996	13	No	2
	596[2]	1996	33	Yes	2
Double-Walled, Fiberglass UST; Double-Walled Underground Fiberglass Piping (11 sites, 26 USTs)	71	1987	61	Yes	2
	332	1988	35	Yes	Unknown
	593	1988	97	Yes	4
	489	1991	42	Yes	Unknown
	470	1994	23	No	4
	405	1995	41	No	3
	490	1995	15	Yes	3
	289	1996	23	Yes	2.5
	594	1998	53.5	Yes	1
	597	unknown	8.5	Yes	Unknown
	586	1996	60	Yes	3
Double-Walled Bare Steel UST; Double-Walled Underground Fiberglass Piping (3 sites, 5 USTs)	437	1987	10	Yes	5
	342	1990	11	Yes	8
	145	1997	8	Yes	1.5
Double-Walled UST Steel-Clad with FRP; Double-Walled Fiberglass Underground Piping (6 sites, 11 USTs)	73	1985	63	Yes	3
	261	1988	10	Yes	10+
	596[2]	1996	33	Yes	2
	422	1997	17.5	Yes	2
	556	1997	20	No	1.5
	571	1991	15	Yes	8
Single-Walled Fiberglass UST; Single-Walled Fiberglass Underground Piping (2 sites, 6 USTs)	196	1982	25	Yes	Unknown
	287	1982	73.5	Yes	0.75
Singled-Walled Fiberglass UST; Double-Walled Fiberglass Underground Piping (2 sites, 5 USTs)	595	1982	N/A[3]	Yes	4
	598	1979	17	Yes	3
Double-Walled, Fiberglass UST; Singled-Walled Fiberglass Piping in Trench Liner (2 sites, 6 USTs)	153	1996	14	Yes	Unknown
	592	1984	30	Yes	4

1. Depth-to-water designated using field measurements, pore pressure data from the CPT, and other field observations.
2. Site 596 is included in two system component categories.
3. NA denotes Not Available; access restricted by site owner/operator.

3.0 Methods

The approach for this investigation was designed to collect information regarding both the UST facility and the presence or absence of MtBE in soil vapor, soil, and groundwater at each facility. Consistency of methods between individual sites was important to allow comparison of results across the entire study population. Guidance obtained from the US EPA′s *Expedited Site Assessment Tools for Underground Storage Tank Sites* (US EPA 1997) was used to help develop an investigation approach that was systematic and efficient. The on-site activities for the investigation were conducted in four phases:

- ***Site inspection*** of each site to evaluate access issues (i.e., space limitations), and to establish work areas and schedules with the facility operator, confirm UST system components, identify potential sources of MtBE other than the UST system, and identify utility/piping locations
- ***Cone penetrometer testing*** (CPT) at an average of approximately 3 on-site locations per site, to obtain site-specific information about the depth to groundwater and types of soils at the site
- ***Soil-gas survey*** at 3 to 10 on-site locations per site
- ***Soil and groundwater sampling*** at 1 to 7 locations per site

CPT and soil-gas surveys were not conducted as part of investigation activities conducted in off-site areas. Rather, lithology and depth-to-water data were obtained from continuous core sampling. The reduced scope for off-site activities was in part because of the longer distances from the source area, which would reduce the effectiveness of soil-gas sampling, and because of the logistical constraints of working in streets (i.e., traffic control for multiple mobilizations).

The project team implemented each method at 3 groups of sites (6 to 12 sites per group) to promote consistency among the sites and to allow the data collected from the application of each method to be used to refine application of the next method.

Before conducting field activities, LFR developed a Study Health and Safety Plan (HSP) that was then modified as necessary to develop Project HSPs for each of the individual sites. Activities conducted under LFR′s direction were completed in compliance with applicable Occupational Safety and Health Administration (OSHA) regulations, particularly those in Title 8 California Code of Regulations 5192, and other applicable federal, state, and local laws, regulations, and statutes. LFR obtained applicable drilling permits and identified subsurface structures before conducting investigation activities. LFR also prepared a Study Emergency Response Plan (SERP) to outline immediate response procedures if damage to property occurred during the investigation.

A data management system was also developed to assist in data compilation, organization, storage, review, statistical analysis, and presentation. The database was designed and programmed using Microsoft Access and was made accessible through a local area network (LAN). Modules were written to accommodate user-friendly data retrieval to assist in communication with site owners and operators during site access negotiations and the planning of field activities, the electronic collection of field data, the smooth integration of laboratory data, the systematic download of individual Site Reports *(see Volume 2)*, the application of linear logistic model statistical analysis, and various other data management functions.

3.1 Site Inspections

Inspections were conducted at each of the 28 sites selected for investigation to obtain more detailed data regarding access to field investigation equipment and the UST system layout. Information for sites that granted access also included details concerning system components and operating history. Team personnel assessed and recorded relevant site features, including buildings, UST locations, pump locations, and surface drainage features. Surrounding site uses were also noted. Data forms were developed for this study to promote consistency and completeness of inspection data. Appendix 2 provides examples of 2 forms. These data were used to formulate the initial site conceptual model and site plan.

One of the secondary objectives of the study was to assess if a particular component of the UST system or feature of the site (e.g., USTs, piping, surface infiltration, etc.) is more or less likely to be a potential source of MtBE to the subsurface. To meet this objective, soil-gas, soil, and groundwater sampling points were located to provide data for each UST system component, or target. The targets and their sample designations were as follows:

Table 5 Designation of Sampling Targets

Target	Designation
UST	**U**
Piping	**P**
Dispenser island	**D**
Surface source	**S**
Other	**O**

These sampling points were identified, preliminarily marked, and discussed with the site operator during the site inspection.

3.2 Lithologic/Hydrogeologic Characterization

CPT was used to investigate and document the types of sediments and measure the depth to groundwater beneath each site. These data were used to help refine the subsequent sequences of the field activities and the specific methods used to collect soil and groundwater samples.

Gregg In Situ, of Martinez, California, completed the CPT work under the direction of an LFR State Registered Geologist. The CPT logs and data for each site are provided in individual Site Reports (*see Volume 2)*. The electronic CPT logs were used to create the initial vertical profile schematic for each site, which was used to select soil-gas, soil, and groundwater sampling locations and intervals. Pore pressure dissipation records were also reviewed to identify the approximate depth to groundwater beneath each site. Appendix 3 provides further details about the CPT methodology used.

3.3 Soil-Gas Sampling and Analysis

InterPhase of Los Angeles, California, conducted the soil-gas investigation under the direction of an LFR State-Registered Geologist or Professional Engineer. The soil-gas investigation data were used to evaluate whether petroleum hydrocarbons containing MtBE were present in the vadose zone and to help select locations for soil and groundwater sampling. With consideration of access constraints (e.g., uncertainties in underground utility locations, overhead hazards, etc.), InterPhase collected soil-gas samples at several locations in the immediate vicinity of potential release points at the sites. Those potential release points included:

- Dispenser islands and UST areas
- Piping from the dispenser islands to the USTs
- Beneath observed potential surface pathways, such as cracks in asphalt and/or concrete surfaces near the dispenser islands, seams between concrete and asphalt surfacing, and in the vicinity of storm drain grating

Two to three soil-gas samples were collected from each sampling location at depths determined on the basis of lithologic and hydrogeologic characterization of the site and the depths of the USTs and related underground piping.

InterPhase analyzed the soil-gas samples immediately following collection in InterPhase′s on-site mobile laboratory. InterPhase used EPA Method 8020 to analyze for benzene, toluene, ethylbenzene, and xylenes (BTEX) and MtBE, and Modified EPA Method 8015 to analyze for total petroleum hydrocarbons as gasoline (TPHg). In addition, InterPhase collected one soil-gas sample per site in a Summa canister for analysis by Air Toxics of Rancho Cordova, California, to confirm the results of the EPA Method 8020 analysis conducted by the field laboratory. Air Toxics analyzed the soil-gas samples using EPA Method TO-14 for petroleum hydrocarbons and the fuel oxygenates MtBE, tertiary-amyl methyl ether (TAME), diisopropyl ether (DIPE), ethyl tertiary-butyl ether (ETBE), and tert-butyl-alcohol (TBA). Appendix 3 provides specific details of soil-gas sampling protocols, including procedures to minimize the potential for cross contamination between sampling locations.

3.4 Soil Sampling and Analysis

Following analysis of the soil-gas results, soil samples were collected to provide quantitative data regarding the presence or absence of MtBE and petroleum hydrocarbons in soils. Soil boring locations and sampling intervals were selected on the basis of the soil-gas results; the lithologic and depth-to-water information obtained using CPT; underground utility layout; observations of potential release points; and access constraints (e.g., uncertainties in underground utility locations, overhead hazards, etc.).

Precision Sampling, Inc., of San Rafael, California, advanced soil borings using dual-tube, direct push technology to reduce the potential for cross contamination and to reduce the amount of waste soils generated. At sites where the direct push drill rigs were not effective (i.e., the drill rigs could not push through the subsurface material, typically where gravels were present), soil borings were drilled using a standard hollow-stem auger drill rig equipped with a minimum 6 7/8-inch, outside-diameter hollow-stem auger operated by Gregg Drilling & Testing of Martinez, California, or Spectrum Drilling of Stockton, California.

An on-site LFR State-Registered Geologist directed all drilling. To the extent possible, soil samples were collected on a continuous basis. The geologist inspected soil samples, recorded descriptions of the samples on field boring logs in accordance with the Unified Soil Classification System, and used a photoionization detector (PID) to screen the samples for organic vapors. The individual Site Reports provide lithologic logs for each of the sites (*see Volume 2*). Appendix 3 provides specific details of soil sampling protocols, including procedures for sample packaging, labeling, handling, and transportation as well as procedures to minimize the potential for cross contamination between sampling locations.

Soil samples selected for chemical analysis were submitted to Alpha Analytics of Sparks, Nevada, a California state-certified off-site analytical laboratory. Alpha Analytics analyzed the soil samples for fuel oxygenates and BTEX compounds using EPA Method 8260 and TPHg using Modified EPA Method 8015. One to three soil samples per site where access was granted were also analyzed for moisture content, porosity, bulk density, sieve analysis, and total organic carbon by URS Greiner (formerly Woodward-Clyde) in Pleasant Hill, California and Curtis & Tompkins in Berkeley, California. The individual Site Reports in Volume 2 contain tables, figures, and lithologic logs that provide further details about the soil investigation, and Volume 3 provides laboratory certificates.

3.5 Groundwater Sampling and Analysis

Groundwater samples were collected from soil borings at each site to provide quantitative data regarding the concentration of petroleum hydrocarbons and fuel oxygenates in groundwater. The number of groundwater samples collected depended on the depth to groundwater, lithology, and the rate at which the soil borings could be advanced. Where possible, deeper groundwater samples were collected in vertical profile in the permeable zone beneath the apparent water table to evaluate variations in chemical concentrations with depth.

Groundwater samples were collected using a variety of methods that were selected based on site lithology and drilling equipment used. Depending on site conditions, groundwater samples were also collected using a discrete screen point sampler or temporary PVC slotted casing.

Alpha Analytics analyzed the groundwater samples for fuel oxygenates using EPA Method 8260, and TPHg using Modified EPA Method 8015. These methods are further described in Appendix 3.

3.6 Site Survey

Throughout site investigation activities, LFR collected Global Positioning System (GPS) spatial data for relevant site features and investigation sampling locations at each site. LFR first created site plans from information gathered from a variety of sources that varied from high quality architectural drawings to poorer quality faxes and hand drawn maps. LFR used Trimble′s GPS Pathfinder Pro XR/XRS Mapping System to collect GPS data for sampling locations and selected site features.

Data were collected in ″real-time″ mode, which allows for differential correction to achieve an advertised precision of approximately 1 meter. GPS data appeared generally accurate relative to our site maps, although there were minor offsets relative to site features and a few data points were obvious outliers. LFR contracted with Chaudhary & Associates of Napa, California, licensed surveyors, to collect GPS data from 3 of the Study sites to check LFR′s data. A comparison of spatial data gathered by LFR and Chaudhary indicated that the spatial relationship (relative location) for each location was, with few exceptions, consistent between the two data sets. However, there was an offset between the LFR and Chaudhary data sets. At the direction of the SCVWD, locational data for the Study were collected by LFR.

Locational data were merged into a database with chemical analysis results for the sampling points. GIS was then used to combine the locational data and the initial site plan for review by the appropriate field team member for spatial accuracy. Any adjustments to the sampling locations or field features were recorded in the database for future reference.

3.7 QA/QC of Analytical Data

Appendix 4 provides summary data tables for the soil-gas, soil, and groundwater data obtained during this investigation. Those data were reviewed by LFR in accordance with the procedures outlined in the Quality Assurance Project Plan (QAPP) (LFR 1998).

Table 6 Number of Soil-Gas, Soil, and Groundwater Samples Submitted for Analysis

Laboratory	Sample Type	Number Submitted for Analysis*
InterPhase	soil-gas	342
Air Toxics,	soil-gas split samples	19
Alpha Analytics	soil	378
Alpha Analytics	groundwater	157

*Includes all field QC samples.

Review of the QA/QC data resulted in the following special qualifiers for sample results:

- Detections of MtBE and TBA in sample 505-BH-06-25.0-WO (collected from Site 505) are flagged as estimated values because surrogate spike percent recovery values were outside laboratory control limits.
- BTEX plus oxygenate results for samples 597-BH-04-9.5-25-W-D-X (collected from Site 597) and samples 261-BH-01-22-WP, 261-BH-02-22-WP, and 261-BH-03-22-WP

(collected from Site 261) are flagged as estimated values because the recommended analysis holding time was exceeded. The sample from Site 597 (597-BH-04-9.5-25-W-D-X) was analyzed one day outside of the recommended holding time. The samples from Site 261 (261-BH-01-22-WP, 261-BH-02-22-WP, and 261-BH-03-22-WP) were re-run outside of the recommended hold time to achieve lower reporting limits.

- Sample dilution was necessary because of high concentrations of target analytes for approximately 2% of all soil samples, 13% of all groundwater samples, and 1% of all soil-gas samples, resulting in elevated reporting limits for those samples.

Appendix 3 provides further details concerning data QA/QC procedures applied during this investigation.

3.8 Statistical Data Evaluation Method

A ″linear logistic model″ method of analysis (Selvin 1995) was used to determine the relationship between the presence of MtBE in ground water and the various features or conditions of the UST systems present at the Study sites. For this analysis, the presence or absence of MtBE in groundwater was considered a binary dependent variable (i.e., detected or not detected) that could be related to independent variables (e.g., the kind of vapor recovery system, the nature of vent piping, the number of years since the facility was upgraded, etc.) The linear logistic model equated the probabilities associated with the binary dependent variable (presence/absence of MtBE) to the independent variables (UST features/conditions). Application of the model produced estimates of the odds that the presence or absence of MtBE was associated with a particular system component or condition. The model produced a logarithm of the odds represented by a linear combination of independent variables and provided a set of estimated odds ratios as a summary statistic.

For binary variables, data were evaluated using the Mantel Haenszel procedure (Miller 1981) of a series of 2-by-2 contingency tables to estimate the common odds ratio. In addition, the Fischer Exact Test, which employs hypergeometric probabilities, was applied to find the probability of occurrence of the ratios observed from the 2-by-2 contingency table procedure.

In cases where the independent variables were not binary outcomes, but multiple categorical variables (such as tank manufacturer), a Pearson′s correlation coefficient was calculated. The data were distributed as a chi-square and a correlation coefficient was calculated.

Results of this analysis are presented in Section 4.2 and the analysis is further described in Appendix 5.

4.0 Study Findings

We have organized the Study Findings in five sections, as follows:

- **Section 4.1** presents findings concerning the occurrence of MtBE, the Study's primary objective
- **Section 4.2** presents findings regarding potential release mechanisms, a secondary Study objective
- **Section 4.3** presents findings regarding the fate and transport of MtBE relative to other oxygenates and petroleum constituents, a secondary Study objective
- **Section 4.4** presents an evaluation of the potential influence of the off-site investigations on the overall Study results
- **Section 4.5** presents a comparison of Study results with other MtBE occurrence studies.

The tables in Appendix 4 summarize the soil-gas, soil, and groundwater data obtained from field investigations. These tables are provided for general reference. Table 7 provides a summary of system components and MtBE detections at the study sites. The individual Site Reports in Volume 2 provide more complete summaries of results for each of the sites.

Table 7 Detections of MtBE in Soil and Groundwater Relative to System Components and Site Conditions

System Components	Site ID	Depth to Water (feet)	UST Present before 1998 Upgrade?	Years Since Upgrade (approx.)	Investi-gation On Site?	Frequency of Detection and Range of Concentration of MtBE			
						Soil		Groundwater	
						No. of Samples	Range (µg/kg)	No. of Samples	Range (µg/L)
Double-Walled UST, 100% Methanol Compatible with FRP; Double-Walled Underground Fiberglass Piping (3 sites, 6 USTs)	65	66	Yes	4	Yes	7 of 17	5.1 to 49	0 of 4	—
	505	13	No	2	Yes	12 of 18	12 to 2,400	9 of 9	0.57 to 25,000
	596	33	Yes	2	No	1 of 13	10	0 of 4	—
Double-Walled, Fiberglass UST; Double-Walled Underground Fiberglass Piping (11 sites, 26 USTs)	71	61	Yes	2	No	0 of 7	—	0 of 3	—
	332	35	Yes	Unknown	No	6 of 15	21 to 1,800	7 of 7	3.3 to 26,000
	593	97	Yes	4	Yes	0 of 8	—	0 of 3	—
	489	42	Yes	Unknown	No	0 of 14	—	1 of 6	1.9
	470	23	No	4	Yes	0 of 14	—	0 of 7	—
	405	41	No	3	Yes	0 of 12	—	0 of 5	—
	490	15	Yes	3	Yes	0 of 17	—	0 of 11	—
	289	23	Yes	2.5	Yes	0 of 18	—	0 of 7	—
	594	53.5	Yes	1	No	1 of 11	18	2 of 4	0.55 to 1.6
	597	8.5	Yes	Unknown	No	1 of 20	8.4[1]	6 of 8	1.7 to 27
	586	60	Yes	3	Yes	1 of 14	6.9	0 of 3	—

Table 7 Detections of MtBE in Soil and Groundwater Relative to System Components and Site Conditions

System Components	Site ID	Depth to Water (feet)	UST Present before 1998 Upgrade?	Years Since Upgrade (approx.)	Investi-gation On Site?	Frequency of Detection and Range of Concentration of MtBE			
						Soil		Groundwater	
						No. of Samples	Range (µg/kg)	No. of Samples	Range (µg/L)
Double-Walled Bare Steel UST; Double-Walled Underground Fiberglass Piping (3 sites, 5 USTs)	437	10	Yes	5	Yes	0 of 12	—	2 of 7	8.1 to 19
	342	11	Yes	8	Yes	8 of 13	13 to 140	5 of 8	1.2 to 1,700
	145	8	Yes	1.5	No	0 of 6	—	0 of 4	—
Double-Walled UST Steel-Clad with FRP; Double-Walled Fiberglass Underground Piping (6 sites, 11 USTs)	73	63	Yes	3	Yes	3 of 12	6.9 to 11	3 of 3	9.2 to 6,700
	261	10	Yes	10+	Yes	17 of 18	15 to 15,000	8 of 8	3 to 200,000
	596	33	Yes	2	No	1 of 13	10	0 of 4	—
	422	17.5	Yes	2	No	0 of 14	—	0 of 6	—
	556	20	No	1.5	No	0 of 16	—	0 of 5	—
	571	15	Yes	8	Yes	1 of 20	8.1[1]	0 of 9	—
Single-Walled Fiberglass UST; Single-Walled Fiberglass Underground Piping (2 sites, 6 USTs)	196	25	Yes	Unknown	No	7 of 15	9.1 to 800	4 of 6	1.5 to 8.5
	287	73.5	Yes	0.75	Yes	0 of 8	—	1 of 3	800
Singled-Walled Fiberglass UST; Double-Walled Fiberglass Underground Piping (2 sites, 5 USTs)	595	N/A[2]	Yes	4	Yes	0 of 4	—	No samples collected	
	598	17	Yes	3	Yes	2 of 18	41 to 260	3 of 7	3.5 to 280
Double-Walled, Fiberglass UST; Singled-Walled Fiberglass Piping in Trench Liner (2 sites, 6 USTs)	153	14	Yes	Unknown	No	1 of 12	8.3	0 of 5	—
	592	30	Yes	4	Yes	5 of 12	6.1 to 110	4 of 5	6 to 40

1. Sample collected below designated depth to groundwater.
2. NA - Not applicable, groundwater was not encountered

4.1 Findings Related to Occurrence

Potential for Release. MtBE was detected in groundwater at 13 of the 27 sites from which groundwater samples were collected. MtBE concentrations ranged from approximately 1 µg/L to 200,000 µg/L. Of the 13 sites, 5 sites reported maximum concentration of MtBE over 1,000 µg/L, and 2 sites reported MtBE at concentrations less than 5 µg/L—the State secondary Maximum Contaminant Level.

Table 8 Concentration Ranges and Number of Sites Reporting MtBE in Groundwater, Soil, and Soil Gas

Concentration Range	Number of Sites Reporting MtBE					
	Groundwater(µg/L)		Soil (µg/kg)		Soil Gas (µg/L)	
	MtBE	Benzene	MtBE	Benzene	MtBE	Benzene
0.5-5	2	5	0	0	0	1
6-100	4	2	8	3	5	3
101-1,000	2	0	4	0	4	0
1,000 +	5	0	3	1	0	0
Total Sites	13 of 27	7 of 27	15 of 28	4 of 28	9 of 17	4 of 17

Benzene data are provided for comparison purposes.

As shown, MtBE was detected in groundwater samples at approximately 50% of the sites from which groundwater samples were collected during the Study. Given the lack of any known bias in the sites selected for investigation, these data indicate MtBE may be present in groundwater at approximately 50% of facilities with 1998-upgrade-compliant UST systems throughout Santa Clara County.

Also, MtBE was detected at a greater frequency and higher concentration in soil and groundwater when compared with individual petroleum constituents (e.g., benzene; *see Table 8*). For example, MtBE was detected in groundwater at a maximum concentration of over 1,000 µg/L at 5 sites while benzene was not detected at concentrations above 100 µg/L in any of the groundwater samples collected during the investigation (Table 8). The greater frequency of MtBE detections relative to petroleum constituents likely results from increased solubility and mobility of MtBE; increased vapor pressure of MtBE (i.e., 25 times greater than benzene when corrected for its composition in gasoline); the relatively large fraction of MtBE in the fuel mixture; and recalcitrance of MtBE to biodegradation relative to petroleum compounds. Other oxygenates detected include TBA, TAME, and ETBE (see Table 11).

MtBE also was detected in soil-gas and soil samples collected above the apparent groundwater table during this study. Table 9 provides a comparison of detection of MtBE in soil gas and soil at sites where MtBE was detected in groundwater versus sites where MtBE was not detected in groundwater.

Table 9 Comparison of MtBE Detection in Soil Gas and Soil Relative to Presence or Absence of MtBE in Groundwater

Medium	MtBE Detected in Groundwater 13 Sites Total				MtBE Undetected in Groundwater 14 Sites Total		
Soil Gas	D		D		D		
Soil	D	D				D	
Number of Sites	5	4 (3)	1	3 (2)	2	3 (1)	9 (5)

A ″D″ denotes that MtBE was detected in the identified medium. The numbers in parenthesis denote off-site investigations. Soil-gas samples were not collected at sites where field activities were conducted in off-site areas.

As shown, MtBE was detected in both soil gas and soil at 5 sites, in soil only at 4 sites, and in soil gas only at 1 site, with a total of 10 of the 13 sites that had detections of MtBE in groundwater also having detections of MtBE in soil or soil gas. The Table 9 data suggest that detections of MtBE in both soil and soil gas were good indicators of MtBE in groundwater during this Study.

Effects of Subsurface Conditions. MtBE was detected in groundwater samples collected from sites with various depths to groundwater and lithologies. As noted in Section 2.3, shallow groundwater was defined as less than 35 feet and deeper was defined as more than 35 feet. The fine- and coarse-grained classification was based on a review of the soil boring and CPT data for each site. At sites where both fine- and coarse-grained sediments were present and neither soil type was predominant, the site was classified as coarse-grained.

As shown in Table 10, MtBE was detected in about one half of each of these depth-to-water/lithology categories. This finding indicates that the likelihood of MtBE occurrence in groundwater is not strongly related to lithology or depth to groundwater.

Table 10 Evaluation of Lithology and MtBE Releases

Depth-to-Water/Lithology Category	Number of Sites with MtBE or Benzene in Groundwater	
	MtBE	Benzene
Shallow/coarse grained	3 of 6	1 of 6
Shallow/fine grained	5 of 11	2 of 11
Deeper/coarse grained	3 of 6	1 of 6
Deeper/fine grained	2 of 4	3 of 4
Total Sites	13 of 27	7 of 27

Comparison of Potential MtBE Impacts with Potential Impacts of Other Constituents. As previously described, MtBE was detected at a greater frequency and higher concentration in soil and groundwater when compared with individual petroleum constituents (e.g., benzene; *see Table 8*). No petroleum constituents were detected in groundwater at 5 of the 13 sites that had detections of MtBE. These data reflect the different fate and transport characteristics of MtBE relative to petroleum constituents (see second paragraph of previous discussion).

Other fuel oxygenates also were detected in groundwater samples collected during this Study (Table 11). TBA was detected in groundwater at 3 sites (maximum concentration of 12,000 µg/L), TAME was detected at 2 sites (maximum concentration of 95 µg/L) and ETBE was detected at one site (maximum concentration of 5.2 µg/L). These other oxygenates were detected only in those groundwater samples with a corresponding concentration of MtBE over 1,000 µg/L.

Table 11 Summary of Reported Concentrations of Oxygenates

Site ID	Sampling Location	Sampling Depth	MtBE (µg/L)	DIPE (µg/L)	ETBE (µg/L)	TAME (µg/L)	TBA (µg/L)
332	332-BH-02	33.0-40.0	2,900	< 2	< 2	8.1	< 20
	332-BH-04	35.0-36.0	26,000	< 20	< 20	32	< 200
261	261-BH-01	22.0	200,000	< 1.0 UJ	5.2 J	95 J	< 10 UJ
	261-BH -02	22.0	19,000	< 1.0 UJ	2.7 J	5.0 J	1,100
	261-BH -03	22.0	16,000	< 1.0 UJ	4.4 J	8.1 J	2,300
342	342-MW-01	12.0	1,700	< 4	< 4	< 4	650
505	505-BH-01	25.0	25,000	< 100	< 100	< 100	12,000
	505-BH -06	25.0	2,300 J	< 40	< 40	< 40	1,100 J

Notes:
Volume 3 provides laboratory certificates.
J = estimated value
UJ = not detected at the estimated reporting limit shown

Comparison of the concentration of MtBE with that of the other oxygenates reveals that, with the exception of TBA at Sites 342 and 505, the ratio of the concentration of the other oxygenates to MtBE is relatively low (i.e., less than 0.15). This low ratio of other oxygenates to MtBE suggests that the other oxygenates may represent impurities of the MtBE product, rather than a breakdown product of MtBE, or a mixture of MtBE and another raw oxygenate product. The higher ratios of TBA to MtBE at sites 342 and 505 (approximately 0.4 and 0.5, respectively) may indicate transformation of MtBE to TBA in the subsurface or may reflect the very high solubility of TBA in water.

4.2 Findings Related to Release Mechanism

One of the secondary objectives of the Study was to assess whether a particular component or feature of a UST system is more or less likely to represent a potential source of MtBE to the subsurface. To meet this objective, collected data were assessed for a correlation between UST system components and occurrence of MtBE. Also, an evaluation of the data for ″target samples″ was conducted.

Comparison of Occurrence with UST System Features. A comparison was conducted between those sites with detections of MtBE in groundwater and those sites without detections of MtBE in groundwater to assess for correlation between UST system components and occurrence of MtBE. Table 12 lists the UST system features that were compared and the results of that comparison.

Table 12 MtBE Detections Relative to Facility Characteristics

Parameter	Number of Sites	Sites With MtBE in Groundwater			
TOTAL NUMBER OF SITES:	**27**	**13**			
Prior Release Reported?					
Yes	9	4	of	9	44%
No	18	9	of	18	50%
UST System On Site Before Upgrade?					
Yes	23	12	of	23	52%
No	4	1	of	4	25%
Proximity to LUST Site					
▪ Less than 250 feet	2	0	of	2	0%
▪ More than 250 feet	25	13	of	25	52%
Years Since Upgrade					
▪ 5 Years or less	19	7	of	19	37%
▪ 6 Years or more	3	2	of	3	67%
▪ Unknown	5	4	of	5	80%
Depth to Water/Lithology					
▪ Shallow/coarse grained	6	3	of	6	50%
▪ Shallow/fine grained	11	5	of	11	45%
▪ Deeper/coarse grained	6	3	of	6	50%
▪ Deeper/fine grained	4	2	of	4	50%
UST Construction					
▪ Single-walled	3	3	of	3	100%
▪ Double-walled	24	10	of	24	42%
Piping Construction					
▪ Single-walled	2	2	of	2	100%
▪ Double-walled	23	10	of	23	43%
▪ Lined trench	2	1	of	2	50%
Piping Delivery System					
▪ Suction	3	1	of	3	33%
▪ Pressure	24	12	of	24	50%

Table 12 MtBE Detections Relative to Facility Characteristics

Parameter	Number of Sites	Sites With MtBE in Groundwater			
TOTAL NUMBER OF SITES:	**27**	**13**			
Vapor Recovery System					
▪ Balanced	16	5	of	16	31%
▪ Assisted	11	8	of	11	73%
UST Capacity (gallons)					
▪ Mixed	4	2	of	4	50%
▪ 0-10,000	9	5	of	9	56%
▪ 10,001-15,000	13	5	of	13	38%
▪ 15,001-20,000	1	1	of	1	100%
Under Island Containment					
▪ Present	15	8	of	15	53%
▪ Not present	1	0	of	1	0%
▪ Unknown	11	5	of	11	45%
Monthly Throughput (gallons)					
▪ 0-100,000	8	3	of	8	38%
▪ 100,001-300,000	6	3	of	6	50%
▪ Over 300,001	3	2	of	3	67%
▪ Unknown	10	5	of	10	50%
Ownership					
▪ Private	6	1	of	6	17%
▪ Commercial	21	12	of	21	57%
Single-Walled UST or Single-Walled Piping?					
Yes	5	4	of	5	80%
No	22	9	of	22	41%
UST Manufacturer					
▪ Joor	2	1	of	2	50%
▪ Modern Welding	7	4	of	7	57%
▪ Owens Corning	9	5	of	9	56%
▪ Trusco	2	0	of	2	0%
▪ Xerxes	5	2	of	5	40%
▪ Unknown	2	1	of	2	50%

Results of a qualitative analysis of the data in Table 12 did not reveal a correlation between any particular UST system/component and an increased likelihood of MtBE occurrence in groundwater, with the exception that assisted vapor recovery systems, commercial ownership, and single-walled systems (UST and/or piping) appear to have a relatively high correlation with occurrence of MtBE in groundwater (i.e., 8 of 11, 12 of 21, and 4 of 5 respectively [Table 12]).

A quantitative analysis was applied to assess the correlation between system components relative to the presence of MtBE in groundwater. Table 13 summarizes the results of the linear logistic statistical analysis method (described in Section 3.8 and Appendix 5).

Table 13 Results of Statistical Data Evaluations, Relationships Between Presence of MtBE in Groundwater and UST System Components

Comparison Criteria	Test Used	Odds Ratio or Pearson Chi-Squared Correlation Coefficient	P Value	Statistically Significant Relationship? (P <0.05)
Vapor Recovery System Balanced or Assisted	Odds Ratio	5.87	0.0412	Yes
Prior Release Reported? Yes or No	Odds Ratio	0.8	0.555	No
Fuel System On Site Before Upgrade? Yes or No	Odds Ratio	3.27	0.334	No
Proximity to LUST Site <250 Feet or >250 Feet	Odds Ratio	Not calculated[1]		No
Ownership Commercial or Private	Odds Ratio	0.15	0.0981	No
Piping or UST Single Walled? Yes or No	Odds Ratio	5.78	0.140	No
Piping Delivery System Suction or Pressure or Mixed	Odds Ratio	2	0.529	No
UST Construction Single Walled or Double Walled	Odds Ratio	0	0.0978	No
Years Since Upgrade ≤5 Year or ≥6 Year or Unknown	Pearson	3.42	0.181	No
Piping Construction Single-Walled or Double-Walled or Trench Lined	Pearson	2.36	0.308	No
Throughput (gallons/month) 0-100,000 or 100,001-300,00 or >300,000 or Unknown	Pearson	0.797	0.850	No
Depth to Water/Lithology Shallow/Coarse Grained or Shallow/Fine Grained or Deeper/Coarse Grained or Deeper/Fine Grained	Pearson	0.0539	0.997	No
UST Capacity (gallons) <10,000 or 10,001-15,000 or 15,001-20,000 or Mixed	Pearson	1.77	0.622	No
Under Island Containment Present or Not Present or Unknown	Pearson	1.12	0.571	No
UST Manufacturer Joor or Modern Welding or Owens Corning or Trusco or Xerxes or Unknown	Pearson	2.42	0.788	No

1 Insufficient population to allow calculation.

As shown, the statistical analysis found a significant relationship between the presence of MtBE in groundwater and the type of vapor recovery system. Within the Study data set, the odds of finding MtBE in groundwater beneath an ″assisted″ vapor recovery system is approximately 5.9 times higher than a ″balanced″ vapor recovery system. An assisted vapor recovery system uses vapor pumps to extract slightly more vapor from the automobile gasoline tank than is displaced from the UST during dispensing. In a balanced vapor recovery system, vapor pumps are not used to return vapors to the UST that are displaced during dispensing from the UST.

The apparent correlation between MtBE occurrence and UST system type and facility ownership was not confirmed by the statistical evaluation.

Analysis of Targeted Samples. A comparison of results for samples collected from the various UST system components was also conducted (Table 14). These data indicate that the average concentration of MtBE detected in soil and groundwater samples collected near piping was higher than the MtBE concentration detected in samples collected near dispensers and USTs. This result suggests that piping may be more likely to represent a source of MtBE into the subsurface than USTs or dispensers (*see description of Designation of Sampling Targets in Section 3.1 and Table 5*). It should be noted, however, that the higher mean concentrations reported for the piping samples are influenced by a very high outlier (sample 261-BH-01-19SP, reported concentrations of 1,900 µg/kg and 200,000 µg/L for soil and groundwater, respectively).

Table 14 Correlation of System Components to Detections of MtBE

System Components	Geometric Mean Concentration			
	Soil Gas (µg/L)			
	MtBE	# of ND Samples	Benzene	# of ND Samples
Dispenser	5.1	53 of 67	0.7	61 of 67
Piping	0.52	59 of 60	4.4	47 of 60
UST	0.52	61 of 70	3.5	70 of 70
Surface Source	0.5	9 of 9	3.1	7 of 9
Other	0.5	32 of 32	2.9	29 of 32
	Soil (µg/kg)			
	MtBE	# of ND Samples	Benzene	# of ND Samples
Dispenser	4.0	124 of 145	2.7	141 of 145
Piping	23.2	24 of 40	3.5	37 of 40
UST	4.1	134 of 162	2.5	161 of 162
Surface Source	---	0	---	0
Other	5.5	23 of 31	2.7	30 of 31
	Groundwater (µg/L)			
	MtBE	# of ND Samples	Benzene	# of ND Samples
Dispenser	1.9	29 of 45	0.4	41 of 45
Piping	16.6	7 of 14	0.6	11 of 14
UST	1.0	35 of 54	0.3	52 of 54
Surface Source	---	0	---	0
Other	2.0	8 of 12	0.4	11of 12

Note: Laboratory analysis results below the reporting limit (ND) were taken as one-half the reporting limit. Only primary samples were considered (i.e., duplicates were not included).

Study Results Relative to Timing of MtBE Releases. Completion of a quantitative evaluation of how many of the MtBE detections were the result of a release of MtBE from 1998-upgrade-compliant UST systems is problematic because of the site usage histories of the Study population. Specifically, for the majority of sites included in the Study, it is not known whether the MtBE detected was released before or after the 1998 UST system upgrades were installed, or during installation of the upgrades. For example, 12 of the 13 sites with detections of MtBE in groundwater had a reported UST use before the 1998 upgrade-compliant systems were installed.

However, 4 of the 27 Study sites did not have an operating UST system prior to installation and operation of a 1998-compliant UST system (sites 405, 470, 556, and 505). Results for these sites can be interpreted without uncertainties regarding timing of releases. At Site 505, MtBE was detected in groundwater at a maximum concentration of 25,000 µg/L. MtBE also was detected in soil-gas and soil samples collected from this site at maximum concentrations of 61 µg/L and 2,400 µg/kg, respectively. These soil-gas and soil data indicate that the MtBE detected in groundwater was not from an off-site source. These results demonstrate that an MtBE release can occur at a UST facility with a system that meets 1998 upgrade requirements. The highest concentration of MtBE at Site 505 was detected in groundwater samples collected near a dispenser.

Also, 8 of the sites with MtBE detections in groundwater had never documented or reported a gasoline release. While it is difficult to assume the timing of the release, it appears that the release either was not detected by the monitoring system, or for those sites that had previously replaced gasoline USTs, the release was not detected by UST closure sampling.

Finally, MtBE was detected at relatively high concentrations in soil and groundwater (15,000 µg/kg and 200,000 µg/L, respectively) at Site 261, which had been upgraded approximately 10 years ago (about 1988). The high concentrations of MtBE detected and the length of time that has elapsed since upgrade indicate that the release of MtBE at Site 261 likely took place after the system had been upgraded to a system that complies with the 1998 upgrade requirements.

4.3 Findings Regarding Fate and Transport of MtBE

As described in Section 4.1, MtBE was detected in soil and groundwater more often and at higher concentrations than individual petroleum constituents (e.g., benzene). The greater frequency of MtBE detections relative to petroleum constituents likely results from the increased solubility and mobility of MtBE relative to benzene; possible vapor release and migration of MtBE in vapor phase; relatively large fractions of MtBE in the fuel mixture relative to petroleum compounds; and the recalcitrance of MtBE to biological degradation. For example, of the 13 sites with detections of MtBE, 5 did not have detections of any other petroleum fuel constituents. Conversely, there was only one site that had a detection of benzene (Site 586, maximum concentration of 37 µg/L) without a corresponding detection of MtBE. It is important to note the investigations conducted at this site before this Study and before installation of the 1998 upgrades indicated the presence of benzene and the absence of MtBE in groundwater. These previous data indicate that the benzene detected at this site was possibly the result of a pre-1998 upgrade release.

Evaluation of NAPL. The method of Feenstra et al. 1991 was used to assess whether chemical analysis data for soil and groundwater indicated the presence of non-aqueous phase liquid (NAPL). Measured values of soil-water content, bulk density and total organic carbon, and published values for the Henry's Law constant solids/water partition coefficient for MtBE were used in this analysis. Example calculations of the Feenstra analysis method are provided in Appendix 6.

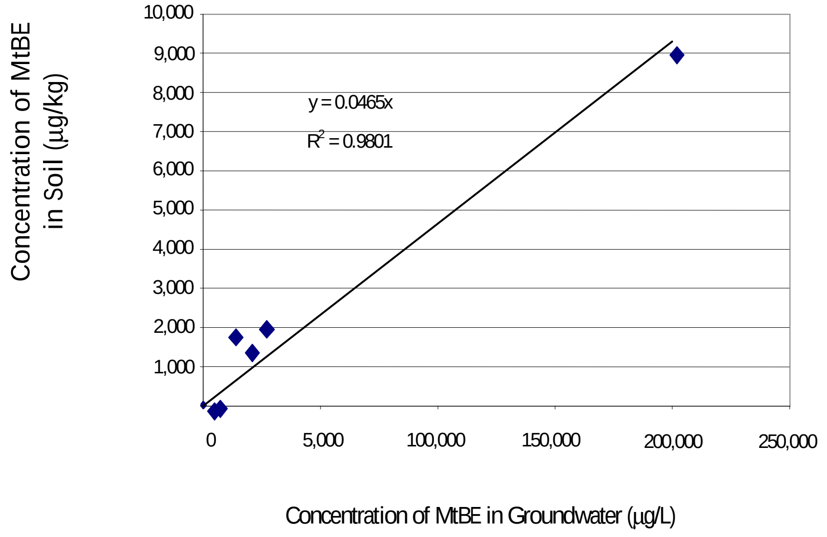
Evaluation of the concentrations of MtBE and petroleum hydrocarbons in soil and groundwater samples indicated that, with the exception of one sample, NAPL was not present in the soil and groundwater samples collected and analyzed during the Study. These data either suggest that petroleum fuel released from the UST system was not released in NAPL phase, or if it was released in NAPL phase, that the NAPL did not migrate to the soil and groundwater sample locations.

Comparison of the Vadose Zone and Groundwater. Nine of the 13 sites with MtBE in groundwater also had MtBE detected in the vadose zone soil samples. The 4 sites with MtBE detections in groundwater and not in the vadose zone had either very low concentrations of MtBE in groundwater (less than 27 µg/L) or, in one case, had a very low sampling density (Site 287). Of the 9 sites with MtBE in soil and groundwater, only one site (505) did not have detections of petroleum hydrocarbons in soil. These data indicate that, for these other 8 sites, MtBE migrated from the UST system into the vadose zone in association with petroleum hydrocarbons.

Three sites had MtBE in soil and not in groundwater (see Table 9). It is interesting to note that the concentrations of MtBE in soil were very low (maximum of only 49 µg/kg) at those 3 sites.

Comparison of Saturated Soil and Groundwater. Chemical analysis data for soil samples collected within approximately 3 vertical feet of a groundwater sample from the same boring were compared to (a) assess correlation; and (b) obtain an empirical correlation coefficient between the laboratory chemical analysis result for MtBE in soil and groundwater if a strong correlation was evident. These data may be useful to help predict an expected concentration in groundwater given a reported concentration in soil. A strong correlation was observed between the concentration of MtBE in soil and groundwater. Soil and groundwater sample pairs selected for this comparison are indicated on the summary soil and groundwater table in Appendix 4. Figure 1 illustrates the results of this comparison.

Figure 1 Correlation of MtBE in Groundwater to MtBE in Saturated Soil



NOTE: For soil and groundwater sample pairs with values below the laboratory reporting limit, a value of 0.5—the reporting limit—was used.

As Figure 1 illustrates, reported concentrations of MtBE in groundwater were strongly correlated with the corresponding concentration in soil (i.e., note correlation coefficient [R^2] of 0.98). Using these data, an empirical soil and groundwater concentration ratio of 0.05 was calculated. [Note: Excluding use of the high outlier shown on Figure 1 resulted in a soil/groundwater concentration ratio of 0.08 and an R^2 of 0.95.] This low ratio of concentrations of MtBE in soil to groundwater reflects the strong tendency for MtBE to reside in the aqueous phase.

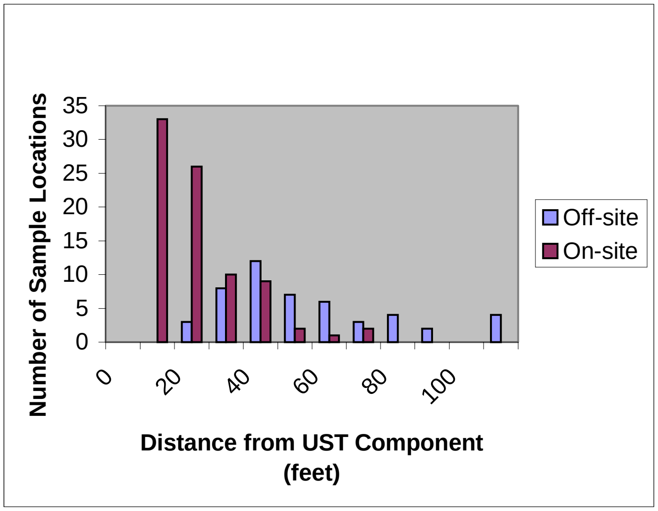
Evaluation of Vertical Distribution. Groundwater samples were collected from different depths within the same boring from 7 sampling locations during the Study to assess for changes in the concentration of MtBE with depth. These samples were collected at 3 discrete depths from 2 borings, and 2 discrete depths from 5 borings. Chemical analysis results for all of the samples collected from 4 of the borings were below detection limits for MtBE. Detected concentrations of MtBE decreased with depth in 2 borings, from 5,400 µg/L (22 feet below ground surface) to 3 µg/L (56 feet below ground surface) in one boring and 220 µg/L (20 feet below ground surface) to 9.3 µg/L (39 feet below ground surface) in the other boring. MtBE increased with depth in one boring, from 280 µg/L (20 feet below ground surface) to 620 µg/L (35 feet below ground surface). No general observations or conclusions regarding vertical distribution of MtBE in groundwater could be drawn from this limited data set.

4.4 Off-Site Investigations

Eleven of the 28 investigations for this study were conducted off site. A comparison of data from on-site versus off-site investigations was conducted to assess for potential effects of the off-site investigations on Study findings.

The distance from each soil/groundwater sampling location to the closest UST system component was measured for each site and entered into the database. Based on these measurements, the average distance of soil/groundwater sampling locations to UST system components for on-site and off-site investigations was 18 and 50 feet, respectively. The histogram in Figure 2 illustrates that, although there is significant overlap between on-site and off-site sampling distances to UST components (especially at the 20- to 50-foot distance), the distribution of off-site sampling distances is skewed toward greater distance from the UST system when compared with the on-site data.

Figure 2 Histogram of Distance from Soil/Groundwater Sampling Locations to UST System Components for On-Site and Off-Site Investigations



However, an evaluation of occurrence data and concentrations-versus-distance data indicate that the increased sampling distance associated with off-site investigations did not result in significant differences between the on-site and off-site investigation findings, or the Study findings as a whole.

For example, the frequency of MtBE detections in soil and groundwater between on-site and off-site investigations was very similar, as shown in Table 15:

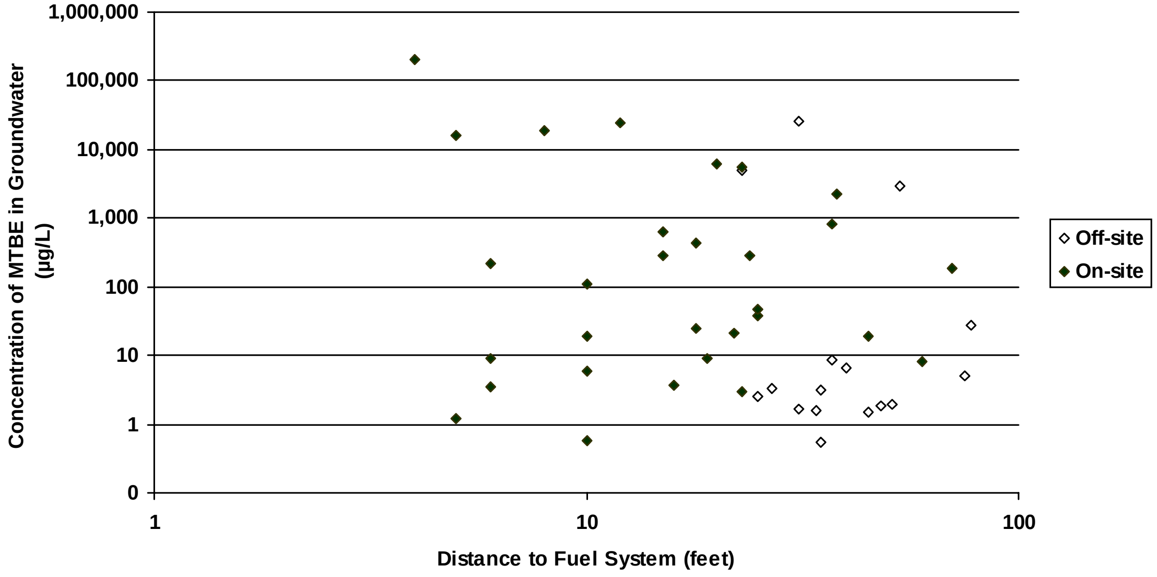
Table 15 Frequency of MtBE Detections for On-Site and Off-Site Investigations

	Sites With Detections of MtBE		Percentage of Sites with Detections of MtBE	
Investigation	**Groundwater**	**Soil**	**Groundwater**	**Soil**
On Site	8 of 16	9 of 17	50%	56%
Off Site	5 of 11	6 of 11	45%	54%
Totals	13 of 27	15 of 28		

These data indicate that off-site investigations did not significantly bias the Study findings regarding occurrence and frequency of MtBE detection.

Also, an evaluation of the concentration of MtBE detected in groundwater versus the distance from the UST system component indicates that use of off-site investigations did not significantly impact the magnitude of MtBE concentrations detected for the Study. The distance-versus-concentration data show a very low correlation between concentration of MtBE detected in groundwater and distance from the UST system, as illustrated in Figure 3.

Figure 3 MtBE Concentrations in Groundwater Relative to Distance from UST System

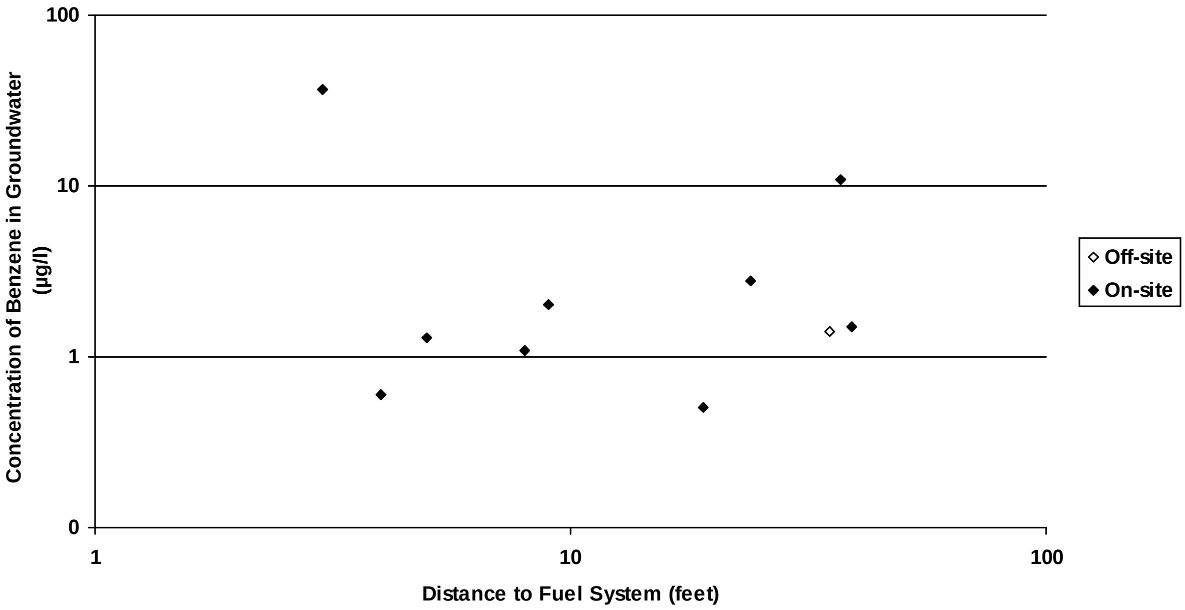


These concentration versus distance data indicate that although there is a cluster of lower MtBE concentrations for the off-site data points, the concentration of MtBE in groundwater is not strongly correlated with distance from the UST system over the distances investigated during this Study (approximately 5 to 100 feet). This finding supports the conclusion that use of off-site data did not significantly bias the findings of the Study.

It is conceivable that concentrations of MtBE detected in groundwater during off-site investigations may be indicative of higher concentrations in groundwater on site (i.e., closer to the source). At one of the Study sites, a site owner/operator collected data after this Study and found on-site concentrations of MtBE in groundwater up to 1,000 µg/L, while the maximum concentration detected in groundwater samples collected during the Study from the off-site locations associated with that site was 27 µg/L of MtBE.

For comparison, Figure 4 shows benzene concentrations in groundwater versus distance from UST system.

Figure 4 Benzene Concentrations in Groundwater Relative to Distance from UST System



4.5 Comparison with Other Occurrence Studies

Occurrence results for this study were compared with results from other studies available in the literature. As shown in Table 16, the 50% MtBE detection frequency for this study is lower than detection frequencies reported in the literature for other studies:

Table 16 Summary of MtBE Detection Frequency for Other Studies

	Detection Frequency		Location
Study	No. of Operating Sites	No. of Non-Operating Sites	
Happel et al. 1998	78% (236)	NA	California
Buscheck et al. 1998	83% (251)	67% (161)	California
Crowley & Tulloch 1998	83% (180)	59% (234)	California

The lower detection frequency for this Study likely reflects the site selection criteria, which focused on sites where there were no known releases of MtBE based on review of available regulatory records, or where previous releases were considered to have not affected groundwater. In contrast, the literature studies summarized above reflect data from sites with known release and/or ongoing monitoring programs.

Data from this study also were compared with similar data from an ongoing study being conducted by the SCVWD using the SCVWD's fuel leak data set (Table 17).

Table 17 SCVWD Ongoing Study Results, Current MtBE Concentration Ranges in Groundwater

Current Maximum MtBE Concentrations	Number of Sites Reporting MtBE					
	This Study No Known Release		Operating UST at Known Leak Site		Non Operating UST at Known Leak Site	
Not Detected	14 of 27	(52%)	30 of 187	(16%)	115 of 219	(53%)
0.5-5 µg/L	2 of 13	(15%)	5 of 154	(3%)	6 of 104	(6%)
6-100 µg/L	4 of 13	(31%)	25 of 154	(16%)	47 of 104	(45%)
101-1,000 µg/L	2 of 13	(15%)	41 of 154	(27%)	36 of 104	(35%)
1,000 + µg/L	5 of 13	(38%)	86 of 154	(56%)	15 of 104	(14%)
Total Sites	13 of 27	(48%)	154 of 187	(82%)	104 of 219	(47%)

This table provides MtBE data for groundwater from 3 populations. The first population (this Study) represents 27 operating UST facilities with no known MtBE releases. The second population represents 187 operating UST facilities where a release has been reported and groundwater is actively being monitored for MtBE. The third population represents 219 sites where USTs are no longer being used for gasoline storage, but a known release was reported and groundwater is being actively monitored for MtBE. The latter two populations reflect the most recent monitoring results.

As shown in Table 17, the operating facilities with known leaks have a higher percentage of MtBE detections (82%) and higher concentrations overall (56% > 1,000 µg/L). The population with next highest percentage of detections (48%) and range of concentrations (38% > 1,000 µg/L) is the population examined in this Study. The population with the lowest percentage of detections (47%) and lowest percentage of sites with MtBE over 1,000 µg/L (14%) does not have operating USTs, but has had a known petroleum release reported.

It is significant that the percentage of detections over 1,000 µg/L for the pilot Study population (38% detections, i.e., 5 of 13) is comparable to the percentage of detections over 1,000 µg/L for the operating facilities with known releases (56% detection, i.e., 86 of 154). These data suggest that potential releases from operating facilities, regardless of previous leak history, must be considered in assessing groundwater vulnerability.

4.6 Application of Study Findings to a Groundwater Vulnerability Assessment

One of the underlying objectives for completing this study was to assess the vulnerability of groundwater in Santa Clara County to MtBE from UST systems that meet 1998 upgrade requirements. The results of this Study indicate that MtBE may be present in groundwater beneath approximately 50% of the UST facility population in Santa Clara County. It is important to note that the 50% occurrence rate measured during this Study cannot directly be applied as a probability of a release from upgraded or new UST facilities. However, it is reasonable to consider the 50% occurrence frequency measured during this Study in evaluating the population of UST facilities in Santa Clara County that are similar to the Study population.

It is significant that 7 of the 13 facilities in this Study with MtBE detections in groundwater are located within approximately 2,000 feet of a groundwater supply well. While these data provide a preliminary indication of vulnerability of drinking water to MtBE impacts, analysis of local and regional hydrogeologic conditions, water supply well locations and screened depths, and groundwater recharge, discharge, and pumping rates would be essential to better understand any resultant vulnerability of groundwater and drinking water resources to subsurface releases of MtBE (API 1999). Also, data regarding the persistence of MtBE in the subsurface environment, and the horizontal and vertical distribution of MtBE in groundwater from specific releases is needed to more fully assess the actual vulnerability of groundwater resources to subsurface releases of MtBE.

5.0 Summary of Key Study Findings

This section provides a brief summary of key findings of the Study. The data that provide the basis for these findings and a description of the methods used to obtain that data are described in Sections 2.0 through 4.0 of this report.

- MtBE was detected in groundwater samples at approximately 50% of the sites from which groundwater samples were collected during the Study. Given the lack of any known bias in the sites selected for investigation, these data indicate MtBE may be present in groundwater at approximately 50% of UST facilities that meet 1998 upgrade requirements throughout Santa Clara County.
- Data collected during this study indicate that the likelihood of MtBE occurrence in groundwater is not strongly related to lithology or depth to groundwater.
- MtBE was detected in groundwater and soil more often and at higher concentrations than individual petroleum constituents. The greater frequency of MtBE detections relative to other petroleum constituents likely results from increased solubility and mobility of MtBE; increased vapor pressure of MtBE; the relatively large fraction of MtBE in the fuel mixture, and recalcitrance of MtBE to biological degradation relative to petroleum compounds.
- Results of this study did not reveal a quantitative correlation between any particular UST facility feature and an increased likelihood of MtBE occurrence in groundwater, with the exception of the vapor recovery system. For the population included in this Study, there was a statistically significant greater likelihood of an MtBE occurrence associated with an ″assisted″ vapor recovery system when compared with a ″balanced″ vapor recovery system.
- Results of this study demonstrated a release of MtBE to groundwater from a facility with a UST system that meets 1998 upgrade requirements and had no prior UST usage.
- A quantitative evaluation of the laboratory chemical analysis data for soil samples indicated that with the exception of one soil sample, NAPL was not present in the soil samples collected. These data either suggest that petroleum fuel released from the UST system was not released in NAPL phase, or if it was released in NAPL phase, that the NAPL did not migrate to the soil sample locations.
- MtBE was detected in soil and/or soil gas at 10 of the 13 sites that had detections of MtBE in groundwater. These data indicate that the presence of MtBE in both soil and soil gas was a good indicator of MtBE in groundwater for this Study.
- A strong correlation exists between reported concentrations of MtBE in groundwater and MtBE concentrations detected in a corresponding saturated soil samples. The low ratio between soil and groundwater MtBE concentrations (0.05) observed for this Study reflects the strong tendency for MtBE to reside in the aqueous phase.

6.0 Recommendations

The data collected during this study should be considered ″occurrence″ data that provide information regarding the presence or absence of MtBE in groundwater beneath UST facilities. These occurrence data provide only a preliminary indication of the potential vulnerability of groundwater as a drinking water resource to MtBE releases. Analysis of local and regional hydrogeologic conditions, water supply well locations and screened depths, and groundwater recharge, discharge, and pumping rates is recommended to better understand the resultant vulnerability of groundwater and drinking water resources to undetected releases of MtBE at operating fueling facilities. Also, data regarding the persistence of MtBE in the subsurface environment and the horizontal and vertical distribution of MtBE in groundwater from specific releases is needed to more fully assess the actual vulnerability of groundwater resources to subsurface releases of MtBE.

Although one of the secondary objectives of the Study was to assess whether a particular UST facility component or condition is more or less likely to represent a potential source of MtBE to the subsurface, this Study was not designed to obtain and did not provide detailed information regarding this issue. Additional research focusing on UST system components and operating practices at UST facilities is recommended to determine if certain system types or components exhibit a significantly greater risk of having undetected releases. Those data analyses could then be extrapolated to the entire population of UST facilities in Santa Clara County.

7.0 Limitations

Although the Study was designed to maximize the probability of detecting MtBE in groundwater from potential sources, there is still the potential that MtBE, or other constituents were present and not detected. Access constraints and the presence of deep groundwater limited the selection and density of sample locations. As a result, the lack of detection of MtBE or other constituents at a UST facility or low concentrations of MtBE detected does not necessarily mean that a release and groundwater impact has not occurred.

Because of previous site usage at the majority of the Study sites (i.e., USTs were present before installation of 1998-upgrade-compliant systems), results of this study do not provide a quantitative evaluation of how many of the MtBE releases detected during this Study can be attributed to UST systems that met 1998 upgrades at the time of the release.

This Study was not designed to determine the mechanism of releases of MtBE to the subsurface. There are numerous causes/release mechanisms that can contribute to the release of MtBE to the subsurface, including but not limited to:

- Operation and maintenance practices
- Surface spills from ″drive-offs,″ topping off, etc.
- UST filling practices
- System installation procedures
- Failures in UST equipment

The results of this study do not provide data regarding the potential release contribution of any one of these or other potential causes of MtBE release to the subsurface.

References

American Petroleum Institute. *MtBE Site Characterization Technical Bulletin*. In preparation.

Buscheck, T.E., D.J. Gallagher, T.R. Peargin, D.L. Kuehne, and C.R. Zuspan 1998. *Occurrence and Behavior of MtBE in Groundwater*. Presented at the NGWA Southwest Focused Ground Water Conference: Discussing the Issue of MtBE and Perchlorate in Ground Water. June 3-4. Anaheim, California.

Crowley, J. and C. Tulloch. 1998. *MtBE Issues in Santa Clara County Ground Water Supplies*. Presented at the NGWA Southwest Focused Ground Water Conference: Discussing the Issue of MtBE and Perchlorate in Ground Water. June 3-4. Anaheim, California.

Feenstra, S., D.M. Mackay, and J.A. Cherry. 1991. A Method for Assessing Residual NAPL Based on Organic Chemical Concentrations in Soil Samples. Ground Water Monitoring Review. Spring. 11(2): 128-136.

Happel, A.M., E.H. Beckenbach, R.U. Halden. 1998. *An Evaluation of MtBE Impacts to California Groundwater Resources*. Lawrence Livermore National Laboratory, UCRL-AR-130897. 77 pp.

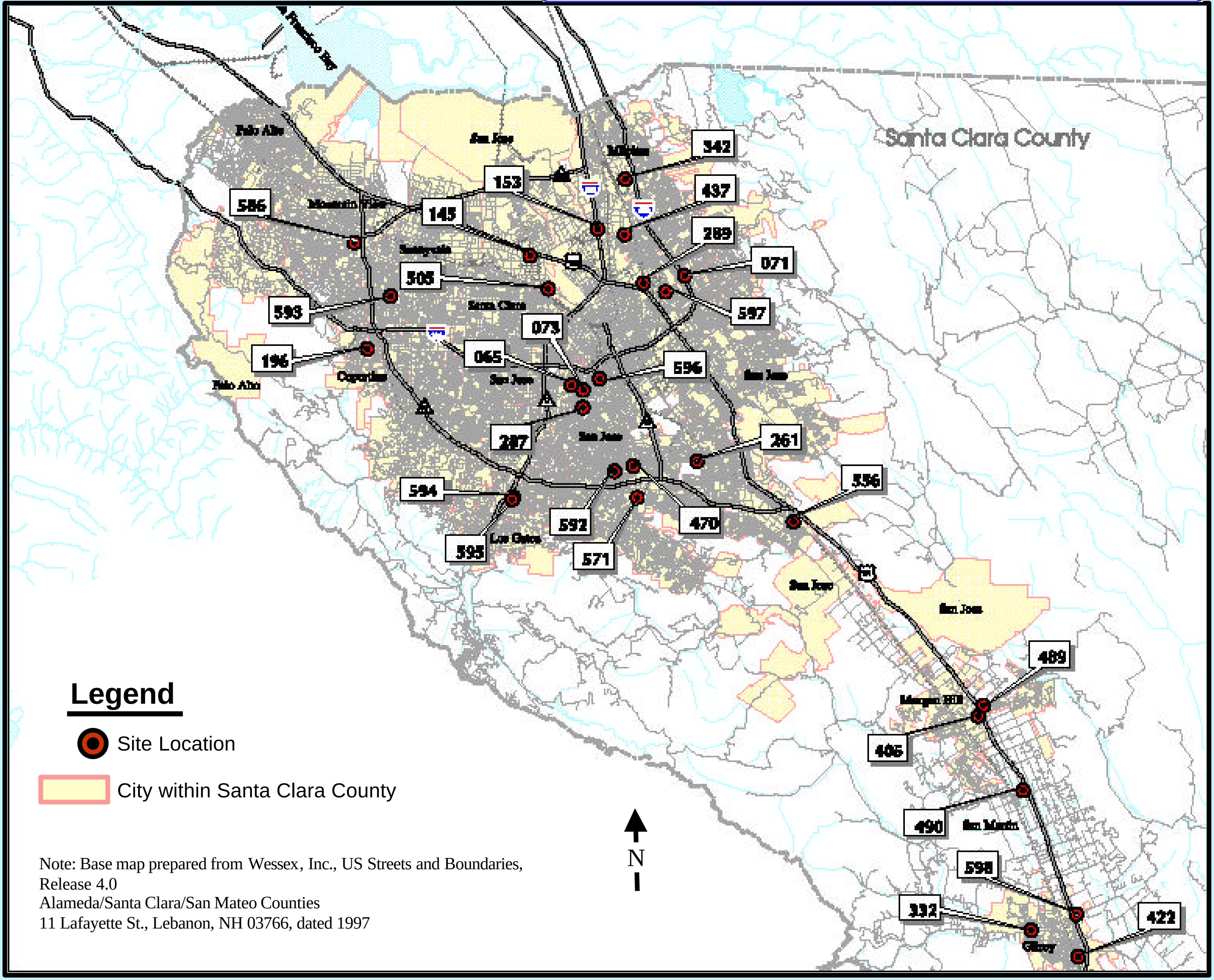
LFR (formerly Levine·Fricke·Recon). 1998. *Quality Assurance Project Plan, Santa Clara Valley Water District Groundwater Vulnerability Pilot Study, Investigate MtBE Occurrence Associated with Operating UST Systems*. October 28.

Miller, R.G. 1981. *Survival Analysis*. John Wiley, New York.

Selvin, Steve. 1995. *Practical Biostatistical Methods*. Duxbury Press. Belmont, California. pp. 365-408

US EPA. 1997. *Expedited Site Assessment Tools for Underground Storage Tank Sites*. EPA 510-B-97-001. Office of Solid Waste and EmergencyResponse. U.S. Environmental Protection Agency, Washington, D.C. March.

Geographic Distribution of Study Sites



Legend

● Site Location

🟨 City within Santa Clara County

Note: Base map prepared from Wessex, Inc., US Streets and Boundaries, Release 4.0
Alameda/Santa Clara/San Mateo Counties
11 Lafayette St., Lebanon, NH 03766, dated 1997